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Sensory Interaction: Evoked Potential Observations in Man

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Summary. Polysensory averaged evoked potentials were evaluated as a function of the interval between a flash and a click which followed it at intervals ranging from 20—120 msec. This was done in two experimental series in each of which the subject's task was to respond manually to the flash. One of these required a choice reaction, namely, withholding of motor response when click was occasionally presented alone.

Both evoked potential amplitude and reaction times showed a linear relationship to interstimulus interval; at shorter intervals, the amplitude of the polysensory evoked response was higher and reaction times were faster.

Topographical analysis indicated that the electrophysiological findings were more consistently obtained in recordings from transverse bipolar leads than from pairs in the anterior-posterior plane. Responses recorded from the left motor region (contralateral to the arm employed in the manual response) showed the effect more consistently than did those from the homotopic recording site on the right motor cortex.

Ratios were calculated between the amplitude of the obtained polysensory evoked responses and a theoretical one expected by algebraic addition of the responses to the two stimuli as presented singly. It was found that ratios were consistently higher for the left motor region when compared to the right. Only at the left was there a reliable relationship between interstimulus interval and the calculated ratio, with values greater than one at short interstimulus intervals and a linear decrement in the ratio value as interstimulus interval lengthened.

Key Words: Multisensory — Evoked potential — Reaction time

Introduction

The intrinsic importance of the topic of polysensory integration and its implications for behavior have been discussed by ROSENBLITH (1961), FESSARD (1961), and JUNG et al. (1963).

Two lines of investigation which up till now have been largely independent have stimulated the present investigation with its focus upon temporal parameters of sensory interaction. One is behavioral. The pairing of stimuli in different sensory modalities may have either inhibitory or facilitatory effects upon motor behavior, depending on the order and interstimulus interval between two stimuli (DAVIS 1959; HELSON 1964). The other is neurophysiological. Multisensory convergence is a property of single cells at many levels of the neuraxis (BUSER and IMBERT

1961; Morrell 1967a; Jung et al. 1963), and evoked potentials to polysensory peripheral stimuli can be recorded in widespread structures with various facilitatory or inhibitory effects (Brazier 1961; Buser et al. 1963; Bignal 1967).

In studies in man, Grey Walter (1964) concluded that there is no interaction between stimuli in different modalities with regard to electrical responses at nonspecific cortical regions; his concept of "idiodromic projection" of auditory and visual stimuli has been supported by Cigánek (1966).

Previous electrophysiological studies on polysensory interaction have been restricted in that no known behavioral significance was attached to the stimuli. In the present study, a visual signal to which the subject is instructed to make a manual response was followed by an auditory stimulus at various intervals. Shorter reaction times occurred at the shorter interstimulus intervals, under conditions in which every trial in the series contained the visual reaction signal (Morrell 1967b) as well as in a series in which on occasion only the auditory stimulus was presented and the subject had to withhold response (Morrell 1968). This report is concerned with possible sensory interaction effects observed in the averaged evoked potentials recorded during these tasks. Some of the specific questions dealt with are: (1) characteristics of the polysensory waveforms in terms of interstimulus intervals; (2) the derivation of the polysensory EP (i. e., is it best described as an algebraic summation at all intervals?); (3) topographical features of the above two issues.

Methods

Subjects were seated in a lounge chair in a dark, sound-deadened and electrically shielded room. Each was instructed to respond as rapidly as possible to trials containing a flash by depressing a small switch lightly taped to his right hand.

Group I: Each session consisted of 252 trials with 36 each of 7 stimulus conditions. Six of these consisted of flash followed by click at the following intervals after flash onset; 20 msec, 40 msec, 60 msec, 80 msec, 100 msec, and 120 msec. The other condition was flash presented alone.

Group II: Each session consisted of 288 trials, with 36 each of 8 stimulus conditions. Seven were identical to those indicated above for Experiment I; the eighth condition was click presented alone, to which the subjects were instructed to withhold response.

The various stimulus conditions were presented in quasi-random order with the constraint that no pattern was repeated on the immediately following trial. Inter-trial times ranged between 4—8 secs. All subjects were given a five-minute warm-up before each session which both familiarized them with the task and established dark adaptation. In each series, a ten-minute rest was given at the halfway point. Subjects were instructed to keep their eyes closed throughout the experiment.

Subjects: All subjects were right-handed normal adults (age range 20—28 years). Records were obtained from 6 subjects for group I, and from 8 subjects for group II.

Stimuli: Stimulus characteristics have been detailed elsewhere (Morrell 1967b; Morrell 1968).

Recording: Silver disc electrodes were placed at O1, T5, T3, F7, A1, C3, C4, A2 and Cz, following the International 10—20 system convention. An electrode on the forehead was connected to ground.

Two orthogonal bi-polar arrays were utilized, one transverse and the other in a posterior-anterior gradient. A 14 channel Ampex DAS—100 system served for amplification and recording of all data, including 10 channels of EEG, visual and auditory stimulus event markers and a pulse initiated by the manual response. The frequency response of the AC pre-amplifiers was flat between 1—500 cps.

Data Analysis: The LINC computer was used for all analysis of data, including A/D conversion, editing of data for possible artifact, averaging and further statistical treatment.

EEG data from each stimulus onset were digitized at a 2 msec sampling interval for a total duration of 1024 msec per trial.

Amplitude Measurement: For each averaged EP, the digital values over a designated epoch from flash onset were summed. Negative values were made positive and added to the cumulative sum, a procedure comparable to integration after rectification. The voltage sum method was used, instead of peak-to-peak amplitude, because consistent identification of particular maxima and minima was not always feasible. The polysensory EPs were of complex morphology and changing latency. Some subjects had well-defined bi-phasic potentials at certain interstimulus intervals. At other intervals, closely spaced multiphasic peaks of approximately equal amplitude appeared.

For each subject amplitudes thus measured for each interstimulus interval were rank-ordered. The rank ordering was essentially the same when a sum-of-squares criterion was applied, but the simple voltage sum seemed more appropriate for the further evaluation of an additive model (see below).

Selection of Epochs of Analysis: Several considerations guided the choice of analysis epochs. (1) The period should be prior to the manual response. (2) Individual subjects varied in average response times; rather than choose different analysis epochs for each subject, a period was sought which was most adequate for the group as a whole. (3) The epoch should include the electrical activity contributed by the click stimulus to the polysensory EP equally at all the interstimulus intervals employed, with allowance for cortical latency.

These considerations were difficult to reconcile completely. Two epochs were evaluated: (a) from flash onset through 256 msec, and (b) one commencing at 140 msec after flash onset (and therefore 20 msec after the longest interval for the presentation of the click) and continuing for another 100 msec.

Results

Amplitude of Evoked Potentials and Interstimulus Interval: Fig. 1 illustrates the averaged EP to single stimuli and to paired flash and click for two subjects in Group I; Fig. 2 shows the results for two other subjects from Group II. Both figures illustrate that the amplitude of the polysensory RP varied systematically

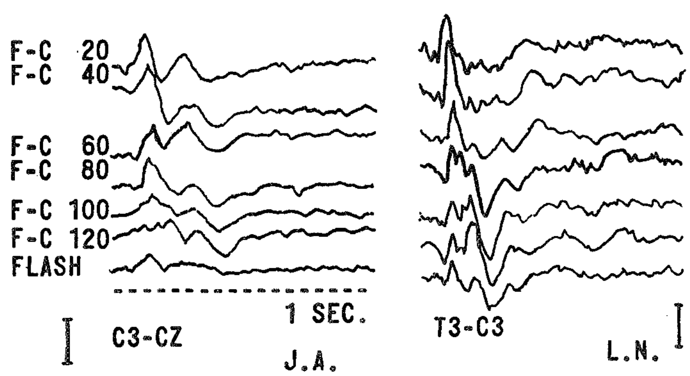

Fig. 1. *Averaged evoked responses to flash-click pairs at various interstimulus intervals; response to flash alone.* Records from two different subjects in experiments in which the subject responded on every trial (Group I)

with interstimulus interval, being greater at the shorter intervals. These results obtained in both the choice reaction and non-choice settings.

In order to quantify these observations and to facilitate topographical analysis the amplitude of each averaged polysensory EP was evaluated, using the voltage sum method described above. This was done for the period starting with flash onset and ending at 256 msec for all derivations and for all subjects. In addition, recordings from the C3—Cz and Cz—C4 linkages were similarly analyzed for the epoch 140—240 msec (with time zero at flash onset). For each subject, for a given derivation, these amplitude scores for the six polysensory EPs were then rank

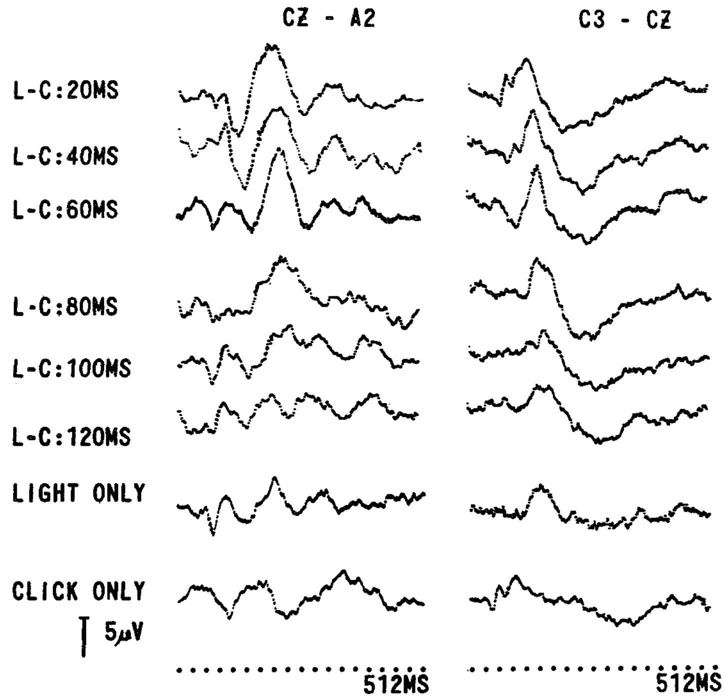

Fig. 2. *Averaged evoked responses to flash-click pairs at various interstimulus intervals, and to flash and click presented singly.* Records from two different subjects in choice RT experiments (Group II)

ordered in terms of magnitude. The average rank order correlation coefficient (rho_{av}) for the pooled data of each of the two experimental groups was then calculated. The results of this analysis are given in Table 1, together with the significance levels.

For both experimental groups, the amplitudes of recordings from the transverse bi-polar pairs T3—C3, C3—Cz, and Cz—A2 were significantly correlated with interstimulus interval. These rho_{av} values ranged from —.44 to —.72. The transverse derivation Al—T3, recorded only in Group II, was also significantly correlated with flash-click interval (rho_{av} = —.65).

Data from the derivation Ol—Cz was significantly related to interstimulus interval in both groups. The Ol—T5 linkage results were not significantly correlated with interstimulus interval in Group I, and showed a low although statistcally reliable relationship in Group II (rho_{av} = —.37). Amplitudes measured at O1—A2 (obtained only from Group II) were not related to the flash-click intervals (rho_{av} = —.13).

Although the amplitude scores measured at the T3—F7 derivation showed a significant average correlation of —.46 with interstimulus interval for the subjects of Group II, the value failed to reach the conventional significance level for Group I. For neither group did activity recorded at the leads T5—T3 and Cz—C4 show a consistent relation to flash-click interval.

The C3—Cz and Cz—C4 derivations were the only symmetrical ones available for evaluation of left vs. right hemisphere differences. For both analysis epochs, and in both groups, activity at the left motor region (contralateral to the hand used in the motor response) showed a consistent relationship to interstimulus interval, while for both groups and for both analysis epochs, activity at the right motor region failed to correlate with this criterion.

Table 1. *Rho_{av} (average rank correlation coefficient) between polysensory evoked potential amplitude and flash-click interval*

Analysis Epoch:	Electrodes	Group I rho_{av} (N)	Group II rho_{av} (N)
0—256 msec	A1—T3	(not recorded)	—.65** (7)
0—256 msec	T3—C3	—.57** (6)	—.63** (7)
0—256 msec	C3—CZ	—.66** (6)	—.59** (8)
0—256 msec	CZ—A2	—.44* (5)	—.72** (6)
0—256 msec	O1—CZ	—.58** (6)	—.46* (5)
0—256 msec	CZ—C4	—.30 (6)	—.16 (8)
0—256 msec	O1—T5	—.24 (5)	—.37 * (7)
0—256 msec	T5—T3	—.34 (5)	—.26 (4)
0—256 msec	T3—F7	—.33 (5)	—.46* (4)
0—256 msec	O1—A2	(not recorded)	—.13 (7)
140—240 msec	C3—CZ	—.41* (6)	—.79** (8)
140—240 msec	CZ—C4	—.01 (6)	—.21 (8)

** Probability of .01 or less that the observed average correlation coefficient could occur if true correlation were zero.

* Probability of .05 for above.

Spearman rank correlation coefficients were first computed for each subject for the relationship between evoked potential amplitude and flash-click interval.

The derivation of the amplitude score is described in *Methods*. The average rho is the algebraic mean of these independent coefficients. (see Taylor and Fong, 1963). The sample size (N) for each calculation was reduced as recording difficulties made particular channels unusable in some subjects.

Evaluation of Facilitation: Having noted that amplitudes of the evoked potentials at certain regions were consistently related to interstimulus interval, the issue of evaluation of facilitation in the evoked response was considered. As an approach to this question, a theoretical evoked potential based upon algebraic addition of the evoked responses to flash and click as presented separately was calculated, with appropriate shifts in the time base. Such measures were available only for the subjects from Group II where click presented singly was one of the stimulus conditions (as well as flash presented singly). For each subject, for a given channel, six theoretical waves were calculated (one for each of the interstimulus intervals used in the experiment). Amplitude scores were then obtained from these theoretical waveforms in the same manner as for the obtained waveforms. The ratio of these two scores was calculated for each flash-click interval. If the ratio was greater than 1, the obtained waveform was of greater integrated amplitude than the theoretical one expected by simple addition.

Fig. 3 shows the mean ratio for eight subjects between the amplitudes of the obtained polysensory EP and the theoretical one as a function of interstimulus

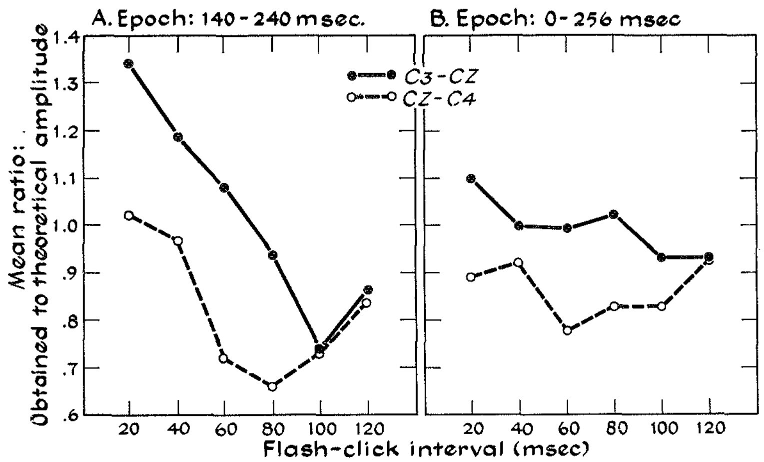

Fig. 3. *Mean ratio, for 8 subjects, of the amplitude of the obtained polysensory waveform to the theoretical one synthesized by algebraic addition of EPs to single flash and single click, at various interstimulus intervals.* Each analysis takes flash onset as time zero

interval. Results are given for two different analysis epochs: (a) initial 256 msec from flash onset (designated 0—256), (b) starting at 140 msec from flash onset, and continuing for another 100 msec (designated 140—240). They are shown for the two symmetrical derivations C3—Cz and Cz—C4.

It may be noted that the ratios are consistently higher for data from the left motor region than for the right for interstimulus intervals less than 100 msec; this finding holds true for both analysis epochs. Subject by subject analysis of this finding is consistent with the mean trend for the group of eight; at each of the interstimulus intervals from 20 through 80 msec, at least six subjects showed a higher ratio at the left motor region than at the right.

Two-way analysis of variance showed that interstimulus interval significantly affected the ratio scores ($P < .01$) only for the left motor region data for the analysis epoch 140—240 msec. Further, for this region and analysis epoch, ratio scores were linearly related to interstimulus interval. ($P < .01$, from linear regression analysis). To summarize: For shorter intervals the ratios were such that the obtained wave was smaller than predicted by an additive model.

The data from the right motor region were not significantly related to interstimulus interval for either analysis epoch.

Latency Changes and Cross-Correlation Functions: Latency to the first positive peak tended to be shortest in the polysensory EPs at 20 and 40 msec interstimulus intervals at all leads where systematic amplitude effects could be noted. However, the changes in waveshape complexity with changing interstimulus interval made it difficult to identify particular components at all intervals reliably for all subjects. Therefore, it was decided to obtain cross-correlation functions between the polysensory EP at the 20 msec interstimulus interval on the one hand, and each of the

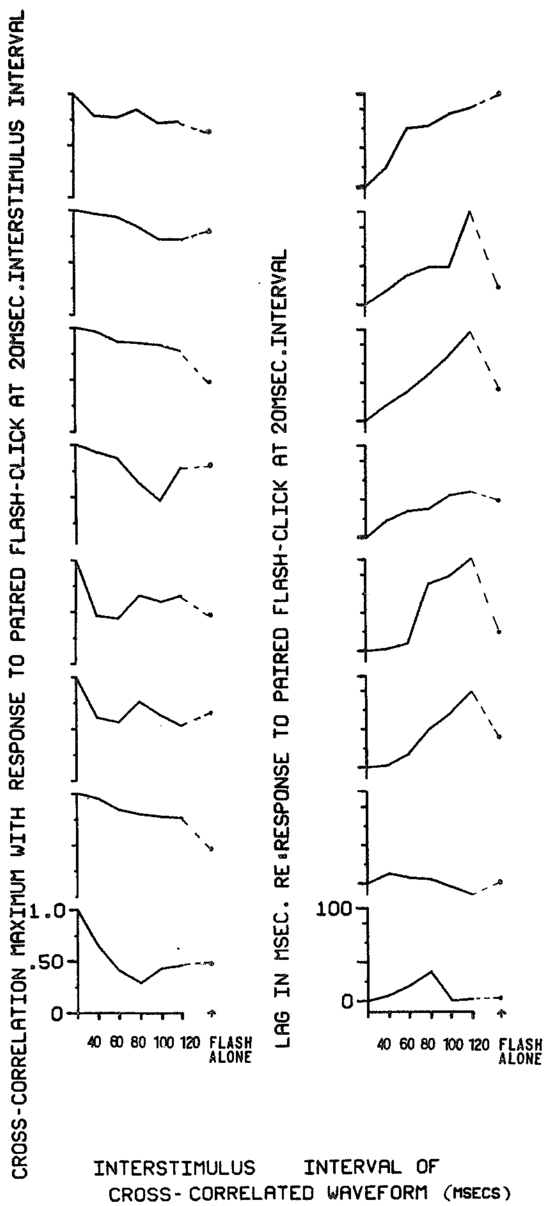

Fig. 4. *Cross-correlation.* Left hand column shows for each of 8 subjects the cross-correlation maximum between the polysensory EP at the 20 msec interstimulus interval and the EP at each of the other intervals (40, 60, 80, 100, 120 msec), and also with the EP to single flash. To the right are the corresponding lag values in msec. at which the cross-correlation maxima occurred for each subject. Cross-correlation functions were obtained over the epoch 40—344 msec. The first point plotted on each graph represents the autocorrelation of the 20 msec waveform, which is 1.0 with a lag of 0. msec. The second point on each right-hand graph represents the cross-correlation maximum between the EP to flash-click paired at 20 msec interstimulus interval and the EP at 40 msec interstimulus interval; correspondingly, on the left is the lag in msec at which the correlation maximum was found. Thus, for the subject record at the top, the cross-correlation maximum for the 20 vs 40 msec comparison was .78 with the lag value at this maximum equal to 20 msec (i. e., if the 40 msec wave were shifted 20 msec back in time, the two waveforms were maximally correlated)

other polysensory EPs on the other; comparison was also made with the single flash EP. This procedure yields a measure of similarity in waveshape and the shift in time of one waveform with respect to another at which maximum correlation is found. Fig. 4 summarizes the results of this analysis for each of the eight subjects from Group II; the data from C3—Cz were chosen since EPs from this derivation had a consistant relationship to interstimulus interval when evaluated in terms of amplitude measures. For most of the subjects, there was a trend for the correlation maximum to decrease with increasing interstimulus interval. The waveform elicited by paired stimuli at the 20 msec interval was more closely correlated with the waveform elicited by stimuli at the 40 msec interval (average correlation maximum = .79) than at the 60 msec interval (average correlation maximum = .71). The correlation maximum between the waveform evoked by the paired stimuli at the 20 msec interval and single flash averaged .60 for the eight subjects.

For six of the subjects, the lag values tended to increase as the comparisons were made with waveforms evoked by increasingly longer interstimulus intervals. Most often the shifts in time for the cross-correlation maxima were somewhat less than the increment in flash-click interval (see right hand graphs). Thus, for example, the average time lag of the EPs at the 40 msec interstimulus interval with respect to the EPs at the 20 msec interval was 11 msec at the cross-correlation maximum; this average includes all eight subjects with individual lag values ranging from 2—20 msec. The average time lag for the EPs at the 60 msec interval with respect to the EPs at the 20 msec interval was 24 msec at the cross-correlation maximum.

Discussion

It has been shown that an auditory stimulus coming after a visual signal to respond reduced reaction time to the visual stimulus; the effect decreased with increasing interstimulus interval (Morrell 1967b; Morrell 1968). Averaged evoked potential measurements, particularly from transverse bi-polar leads placed contralateral to the limb used in the response, showed a correlated pattern. Greatest amplitudes and shortest latencies were observed at the shorter intervals.

It has been observed that the amplitude of the visual EP increases with increase in stimulus intensity, within limits (White and Eason 1966). RTs also are dependent upon stimulus intensity (Woodworth 1938). One hypothesis which may account for the present effects would be that there is an intersensory psychophysical summation which is greater at shorter interstimulus intervals. In support of this hypothesis is the finding that extra stimuli in another modality may affect intensity judgments; an extraneous visual stimulus altered behavior with respect to an auditory stimulus in the same manner as increasing the intensity of the auditory stimulus (Dorfman and Miller 1965).

Alternatively, or in addition, the effect may be mediated after the decision to the flash has been initiated. Neural events prior to and during movement initiation have some dispersion in time (Kornhuber and Deecke 1965; Evarts 1966; Gilden et al. 1966). It is possible that the added auditory input shortens the rise time to threshold of pre-movement processes already set in motion by the flash. The facilitative effects of the added click upon visual RT extend to a 120 msec interstimulus interval even when the subject's task is to withhold response to click presented alone, thus suggesting that the effect may occur relatively late in the total input-output processing period.

The topographical analysis of the EPs is also consistent with the hypothesis that the intersensory effects are closely related in time to motor processes. A systematic relationship between evoked potential amplitude and interstimulus interval was more consistently observed at the left motor region than at the right. Facilitation of the polysensory evoked response, as measured by the ratio of the amplitudes of the obtained wave to one synthesized by algebraic summation, was also more often found at the left than at the right motor area. A systematic relationship between this measure of facilitation and interstimulus interval was found for the left motor region data, and not for the right. The epoch of analysis for which this latter effect was noted was 140—240 msec (with time zero at flash onset). Most commonly, the prominent wave during this epoch was a bi-phasic one with a long negative phase. Since reaction times averaged 260 msec for Group II (MORRELL 1968), this would place the epoch as mainly pre-motor. A similar waveform has been observed by KORNHUBER and DEECKE (1965) and GILDEN et al. (1966) preceding voluntary movement without peripheral stimuli; in both of these studies the potential was found to be more prominent in the contralateral hemisphere.

There is other evidence for the motor system as a site of intersensory convergence. WALL et al. (1953) reported that a light flash potentiated pyramidal tract responses when it occurred 35—150 msec before direct stimulation of the motor cortex; this effect was maximal between 40—60 msec and persisted after occipital lobe ablation.

Buser and his colleagues (BUSER and IMBERT 1961; BUSER et al. 1963) have shown that the motor cortex receives afferent projections from various sense modes; paired visual and auditory stimuli at brief intervals led to motor cortex and pyramidal responses of far greater amplitude than a sum of the responses to each stimulus as separately given.

The present findings also indicate interaction between the neuroelectric responses to auditory and visual stimuli at non-specific and motor cortical regions. At the shorter interstimulus intervals the polysensory EPs as recorded at the motor cortex contralateral to the limb used in manual response tended to be of greater amplitude than predicted by simple summation; it is at these intervals that the greatest facilitation of manual reaction times was noted. As the interstimulus interval was lengthened and the intersensory effect upon RT diminished, the polysensory EPs tended to be of lesser amplitude than expected on the basis of summation.

The nature of the interaction process, as measured electrophysiologically, may depend upon the information handling requirements of the task facing the subject. It would be of interest to measure EPs to polysensory stimuli with a task instruction reversed from that used in the present study. When manual response is to be made to the second of two stimuli, it has been found that the shorter the interval between the extraneous and the reaction eliciting stimuli, the longer the RT (DAVIS 1959). If EPs were assessed in this setting, comparison could then be made between the electrical responses to identical polysensory stimuli where in the one case there is facilitation of motor response and in the other a delay or inhibition.

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